Data Center Energy Benchmarking:

Part 4 - Case Study on a Computer-testing Center (No. 21)

Final Report

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1 Executive Summary

The data center in this study had a total floor area of 8,580 square feet (ft^2) with one-foot raised-floors. It was a rack lab with 440 racks, and was located in a 208,240 ft^2 multi-story office building in San Jose, California. Since the data center was used only for testing equipment, it was not configured as a critical facility in terms of electrical and cooling supply. It did not have a dedicated chiller system but served by the main building chiller plant and make-up air system. Additionally, it was served by a single electrical supply with no provision for backup power. The data center operated on a 24 hour per day, year-round cycle, and users had all hour full access to the data center facility.

The study found that data center computer load accounted for 23% of the overall building electrical load, while the total power consumption attributable to the data center including allocated cooling load and lighting was 30% of the total facility load. The density of installed computer loads (rack load) in the data center was 63 W/ft^2. Power consumption density for all data center allocated load (including cooling and lighting) was 84 W/ft^2, approximately 12 times the average overall power density in rest of the building (non-data center portion).

For the data center, 75% of the overall electric power was the rack critical loads, 11% of the power was consumed by chillers, 9% by CRAH units, 1% by lighting system, and about 4% of the power was consumed by pumps. The ratio of HVAC to IT power demand in the data center in this study was approximately 0.32.

General recommendations for improving overall data center energy efficiency include improving the lighting control, airflow optimization, and control of mechanical systems serving the data center in actual operation. This includes chilled water system, airflow management and control in data centers. Additional specific recommendations or considerations to improve energy efficiency are provided in this report.

2 Review of Site Characteristics

The data center (DC #21) in this study had a total floor area of 8,580 square feet (ft^2) with one-foot raised-floors. It was a rack lab with 440 racks, and was located in a 208,240 ft^2 multi-story office building in San Jose, California. Since the data center was used only for testing equipment, it was not configured as a critical facility in terms of electrical and cooling supply. The data center did not have a dedicated chiller system but was served by the main building chiller plant and a make-up air system. Additionally it was served by only a single electrical supply with no provision for backup power in the event of a power outage. The center operated on a 24 hour per day, year-round cycle, and users had full access to the data center facility at all hours.

Electric power was supplied to the office building from the utility to a single three-phase, 21 kV primary utility service that was transformed through two 2500 kVA transformers to two 4,000A, 480V/277 V main service switchboards. The switchboards provided building electrical distribution to the data center. The data center is fed from main switchboards MSB-16.1 and MSB-16.2. Each switchboard fed two 480V - 208/120V transformers that each supply distribution panels within the data center. There was no standby generator, uninterruptible power supply (UPS), static switch, or electrical reliability component associated with typical data centers. Communication and power wiring was installed at overhead ceiling. Fire sprinklers were provided under the raised floor and at the ceiling.

Cooling for the data center facility was served by the building's main chiller plant and the make-up air system. The building chilled water system included five air-cooled chillers with chilled water pumps. The cooling system inside the data center included eight Computer Room Air Handling (CRAH) units. Seven CRAH units were in operation during the study and received chilled water from the chiller plant serving the whole building. The CRAH's used a down-flow type supply for air distribution, and return to the top without ducts. Figure 1 shows a view of a typical rack lineup in the data center.

The data for this benchmarking exercise was collected during a one week monitoring period in December 2004. The data was collected using the following measurement instruments: HOBO loggers, Elite loggers, Fluke 41B power meter and the installed Automated Logic Corporation (ALC) direct digital control (DDC) system.

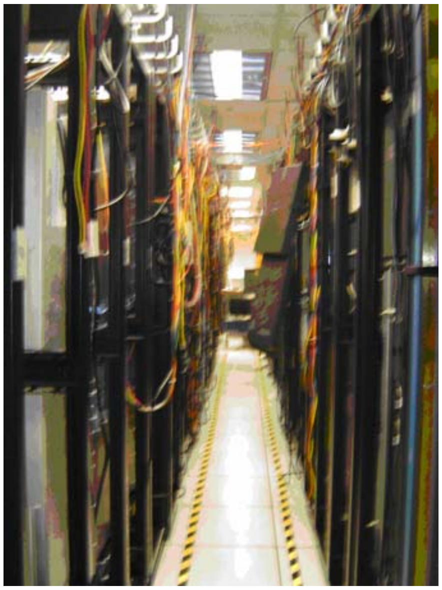

Figure 1 Typical computer rack lineup in the data center

2.1 Electrical Equipment and Backup Power System

Electrical power to Data Center #21 was served by the building electrical distribution system, which received power from Pacific Gas and Electric Company via a three-phase, three-wire, 21-kV main service. The 21 kV utility power was routed through utility metering to a 21 kV switchgear lineup and was transformed to 480/277 V power via two 2500 kVA transformers, which fed two 4,000-A, 480/277 V, 3-phase, 4-wire main service switchboards (MSB 16.1 and 16.2), as shown in the Electrical System One-line Diagram in Appendix B.

As part of the study, the overall building power consumption was monitored over an one-week period in December 2004. During that period, the average amount of power consumed in the building during peak usage (workday) periods was 2,380 kW.

The main switchboards, MSB 16.1 and MSB 16.2, supply power to the data center computer racks through four 225 kVA transformers, two supplied from each switchboard. Each transformer fed an associated 800-Ampere 120/208-V distribution panel, and each of which fed multiple sub-panels within the data center.

The chillers, pumps, CRAH units, lighting and miscellaneous loads are fed from MSB 16.1 via MCC's and other panels.

2.2 Mechanical System

2.2.1 Chiller

The data center, along with the remainder of the building, was designed to be cooled by two 500-ton York Millennium Model Number YTJ1C3E2 water-cooled centrifugal chillers. A third chiller, CH-3, was being installed at the time of the survey. The chillers were arranged in a parallel configuration. CH-1 and CH-2 were operating at the time of the survey. The chilling system flow diagram is shown in Appendix B.

These chillers were installed on the roof of the building along with the other chiller plant components including cooling towers and pumps. The chillers were single-stage centrifugal compressor with modulating capacity of design air conditioning loads (10% to 100%). The chillers were set to maintain a leaving water temperature of 44 °F and were controlled via a stand-alone microprocessor based control to provide optimal chiller efficiency based on a variety of factors including condensing water temperature, evaporator temperature, chilled water set point, motor speed, and pre-rotation vane position.

The chilled water temperature reset was internal through programming of the stand-alone chiller controller. The chiller design parameters were based on 800 gpm of evaporator flow (1.6 gpm/ton) and 1,500 gpm of condenser flow (3 gpm/ton) with an entering (return) chilled water temperature of 59°F and a leaving (supply) water temperature of 44°F. The chilled water average supply and return temperatures measured during the monitoring period were 44.3°F and 52.3 °F respectively, equating to an average temperature differential of 8°F. The delta-T corresponded to 267 cooling tons per chiller, or a total of 533 $tons_R$ for the two chillers. This represented approximately 53% of the design capacity for the two chillers in operation. The chillers were provided with variable speed drives and thus operated efficiently at low loads. The design chiller power demand was 0.42 kW per cooling ton, while the actual power demand during the monitoring period was 0.44 kW per cooling ton.

2.2.2 Chilled Water Pumps

Primary chilled water was circulated by three parallel in-line Bell & Gossett pumps, each with a motor capacity of 15 HP. The pumps were constant speed and identified as CHP16-1, CHP16-2 and CHP16-3. One pump per chiller operated continuously when chillers were in operation, and one pump was provided as a reserve unit. An additional primary pump CHP16-7 was being added at the time of the survey in conjunction with installation of the third chiller. The primary pumps were controlled through the facility Automated Logic Control (ALC) and start/stop with the chillers.

The building chilled water was circulated by the secondary chilled water pumps that consisted of two parallel, in-line, 50-HP, Bell and Gossett centrifugal pumps identified as CHP16-4 and CHP16-5. Both of the secondary chilled water pumps were fitted with VSDs. An additional

50-hp secondary pump, CH 16-6 was being added at the time of survey. The secondary chilled water pumps were controlled in stages based on building cooling demand and controlled based on chilled water return temperature as sensed by the facility Automated Logic Control.

2.2.3 Cooling tower

There were four, Baltimore Air Coil model 3485 series V, cooling towers; CT16-1, CT-16-2, CT16-3 and CT16-4. Each tower was fitted with a 30-hp fan operating on a variable speed drive. The speed of the fans was controlled on cooling tower leaving water temperature (condenser water supply temperature). There was no temperature reset strategy on the cooling towers. The cooling towers were induced draft towers with a design-wet bulb temperature of 68°F, and a leaving and entering water temperature of 73°F and 82°F respectively. Two cooling towers were operational at the time of the study

The cooling towers were served by three, 40-HP, parallel, base-mounted, Bell and Gossett centrifugal pumps. The pumps were identified as CTP16-1, CTP16-2 and CTP16-3. A fourth cooling tower pump, CTP16-4 was being added at the time of the survey. The cooling tower pumps were constant speed and controlled by the condenser water return temperature.

2.2.4 Computer Room Air Handling Units

Seven out of eight 30-ton Computer Room Air Handling (CRAH) units were in operating in the data center, supplying the data center with cold air from the one-foot raised floor. The CRAH's were Pomona Air Model # PW 3000 units. No reheat coils or humidifiers were included in the CRAH units. The CRAH units had 4-inch throwaway air filters located at the top of the unit, rated at 85% efficiency. Each CRAH unit's internal controls were set to maintain temperature and relative humidity set-points of 70°F and 20% RH, respectively, measured at the unit's return air intake.

Based on manufacturer's specification information supplied by the Building Engineer, each air handler has a capacity of approximately 15,000 cfm (cubic feet per minute). The measured power consumption per cfm of air flow of the CRAH's was 0.62 W/cfm. Therefore, the average Air Handler Efficiency-1 was 1620 cfm/kW, based on design airflow. The actual airflow rate was not measured but was calculated as described below.

The space temperature set points were 71°F and 50% relative humidity (RH). Space temperature and RH were recorded at two different locations in the data center, the first location averaged 71°F and 25% RH while the second location averaged 79°F and 25% RH. The average supply temperature from all seven units was 53°F and the average return air temperature was 74°F. Supply relative humidity averaged 64%, while return relative humidity averaged 32%.

Based on average supply and return temperatures, cooling load attributable to the data center racks (175 tons), CRAH's, and lighting power consumption, average airflow rate was estimated to be 13,400 cfm per CRAH.

Average supply and return air temperature and relative humidity for the individual CRAH units are shown in Table 1. These were average readings taken over several days of monitoring.

Table 1 CRAH Unit Supply and Return Air Temperature and Relative Humidity

CRAH Unit	Supply Air (°F)	Supply RH (%)	Return Air (°F)	Return RH (%)
16CAH4	53	61	78	23
16CAH5	51	n/a	75	29
16CAH6	51	n/a	75	29
16CAH7	52	64	71	31
16CAH8	53	n/a	72	35
16CAH13	55	n/a	76	48
16CAH14	53	67	77	34

3 Electric Power Consumption Characteristics

Table 2 shows the end-use electricity demand of the building housing the data center in this study, based on the measurements taken during the monitoring period. The average building electrical load of 2,380 kW was recorded from building instruments. From these measurements, it was observed that 61% of the electrical load was consumed by areas of the building other than the data center and chiller plant, 14% by the chillers and chilled water plant, 23% of the load was consumed by the data center computer equipment, 3% of the load was consumed by the data center CRAH units, and less than 1% of the power was consumed by the data center lighting.

Table 2 Power demand breakdown in the data center building

Power Demand Breakdown	Average Power Consumption (kW)	% Power Consumption
Overall Building Load	2380	100%
Building – non data center & non-chilling Load	1441	60.5%
Data Center Computer Load	540	22.7%
Computer Room Air Handlers	65	2.7%
Building Chiller Plant Pumps and Cooling Towers	92	3.9%
Building Chillers	232	9.7%
Data Center Lighting	10	0.4%

Table 3 shows the power density for the square foot area served by each load. About 70% of the electrical load was consumed by other areas of the building than the data center, including total cooling systems. For the remaining 30% of power consumption, approximately 23% of the building load was consumed by the data center computer equipment and about 7% of the load was by the CRAH units and the data center allocation of chiller and chilled water pump loads. The density of installed computer loads (rack load) in the data center was 63 W/ft^2. Power consumption density for all data center load (including cooling and lighting) was 84 W/ft^2, approximately twelve times the average overall power density in rest of the building (non-data center portion).

Table 3. End-Use of Electricity of the Data Center Building

Description	Electric power demand (kW)	Share of electric energy use (%)	Floor Space (ft2)	Electric power density (W/ft2)
Overall Building Load	2380	100%	208,240	**11**
Chillers – (non Data Center chiller load)	156	6.6%	199,660	0.8
Chiller Plant Pumps & Towers – (non Data Center load)	62	2.6%	199,660	0.3
Building Other - (non DC load &non-HVAC building loads)	1441	60.5%	199,660	7
Total Non-Data Center Load	1659	69.7%	199,660	8
Data Center Computer Load	540	22.7%	8,580	**63**
Data Center CRAH Units	65	2.7%	8,580	7.6
Chillers – (Data Center load)	76	3.2%	8,580	8.9
Chiller Plant Pumps & Towers – (Data Center load)	30	1.3%	8,580	3.5
Data Center Lighting	10	0.4%	8,580	1.2
Total Data Center Load	721	30.3%	8580	**84**

The end-use breakdown for the data center's electric power demand is also shown in Table 4. For the data center, 75% of the overall electric power was the rack critical loads, 11% of the power was consumed by chillers, 9% by CRAH units, 1% by lighting system, and about 4% of the power was consumed by pumps. The ratios of HVAC to IT power demand in the data centers in this study were approximately 0.32.

Table 4. End-Use of Electricity of the Data Center

Description	Electrical Power Consumption (kW)	Percent of Total Data Center Load
Data Center Computer Load	540 kW	75%
Data Center CRAH Units	65 kW	9%
Chillers – (Data Center load)	76 kW	11%
Chiller Plant Pumps & Towers – (Data Center load)	30 kW	4%
Data Center Lighting	10 kW	1%
Total Data Center Load	721 kW	100%

3.1 Power System

Electrical power for the data center was supplied from Main Switchboards MSB-16.1 & 16.2 (Appendix B includes the electrical single-line diagram). Each switchboard fed two 225 kVA, 480V:120/208V Cutler Hammer, dry-type, transformers (model Number N48M28T22A). Each transformer fed an 800A, 120/208V, 3-phase, 4-wire distribution panel. The 800A distribution panels each fed multiple sub-panels for computer racks within the data center.

The chillers, pumps, CRAH units, lighting and miscellaneous loads were fed from MCC's and other electrical panels.

3.2 Chiller System

Electric power demand was monitored for the two parallel operating chillers within a two-week period. CH-1 was operating at the time of survey, however CH-2 was off for the first six days of the monitoring period and then it was placed in operation. Chillers CH-1 and CH-2 had relatively equal loading, when they were both in operation, with average power consumption of 113 kW and 119 kW, respectively. The total chiller power consumption for the period averaged 232 kW.

Total average chiller power demand for the period was 83 kW, which represented the chilling load of the whole building. CH-1 and CH-2 provided the majority of the cooling load with average power demand of 38 and 32 kW, respectively. The chiller CH-5 operated with a power demand of 13 kW.

Figure 2 shows the total chiller power demand and outside air temperatures within the two-week period. The chiller power consumption has been divided by 10 for the plot in order to provide better illustration in scaling between ambient temperature and power. As the outside air temperature changed, the actual chiller power demand also changed accordingly.

In addition, Figure 3 further shows the general correlation of total chiller power consumption and outside air temperature. While showing somewhat correlation between ambient temperature and chiller power consumption, both figures indicate that the chiller load was not only affected by the ambient temperature but influenced by other factors.

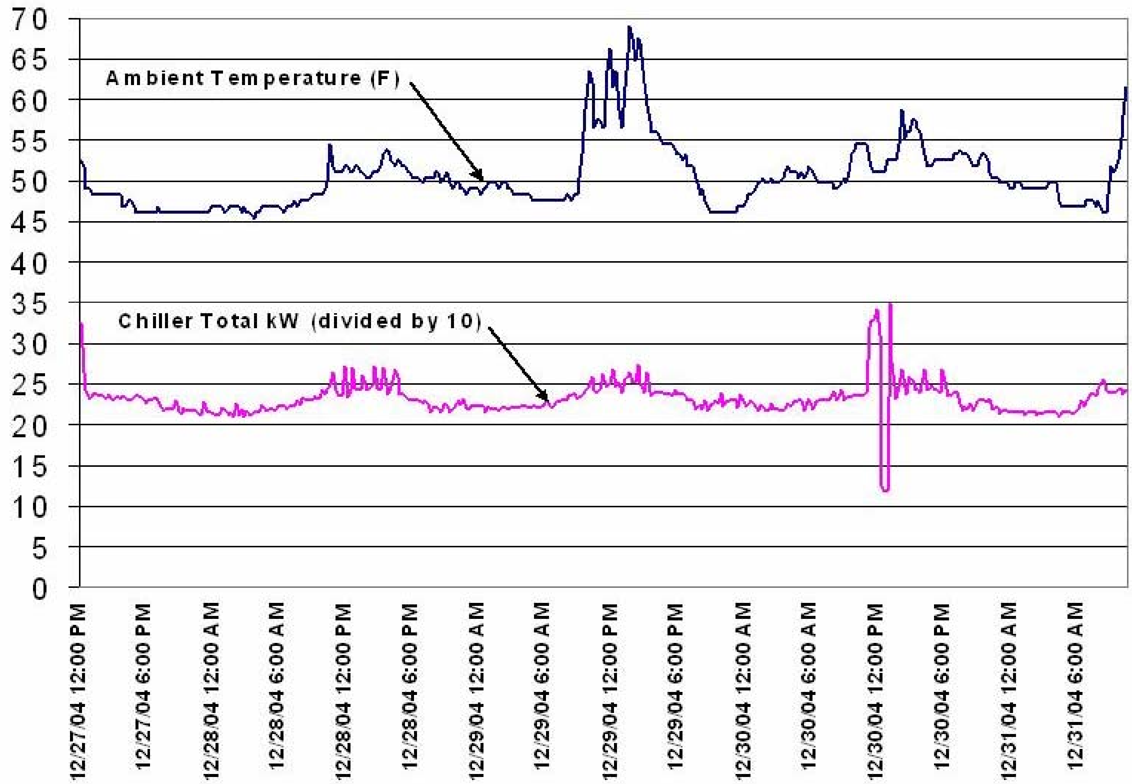

Figure 2 Chiller cooling power and outdoor air temperature

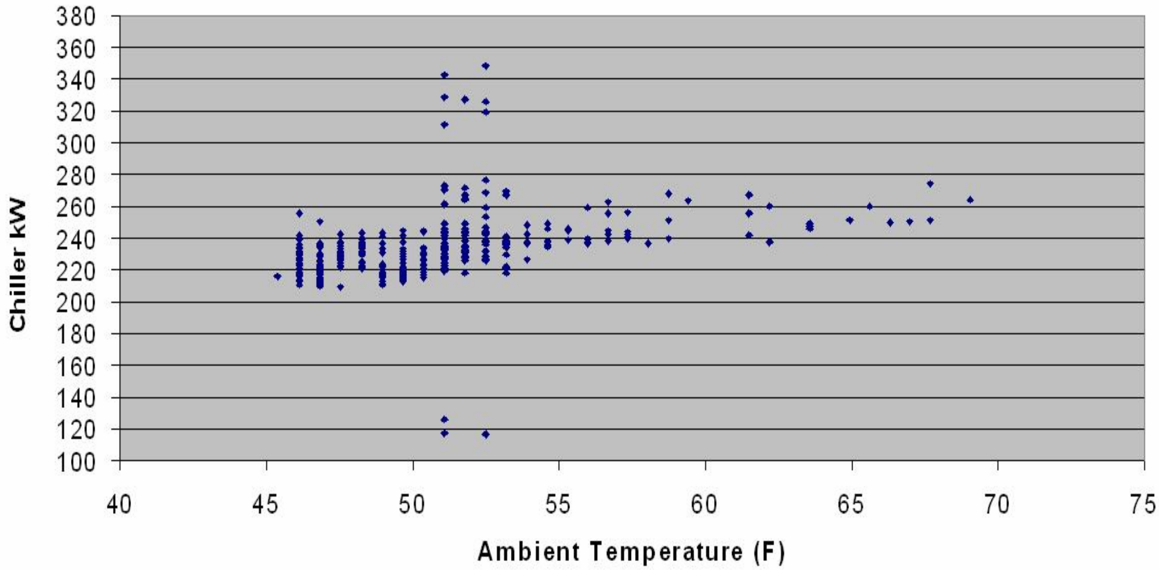

Figure 3 Correlation of chiller cooling power and outdoor air temperature

3.3 Pumping System

The central plant primary chilled water pumping system consisted of three 15-hp primary chilled water pumps: CHP16-1, CHP16-2 and CHP16-3. One pump was designated as a standby unit. An additional primary pump (CHP16-7) was being added at the time of the survey to serve the third chiller that was being installed.

The secondary chilled water pumping system consisted of two 50-hp centrifugal pumps: CHP16-4 and CHP16-5. A third secondary pump (CHP16-6) was being added at the time of survey. The secondary chilled water pumps are fitted with variable speed drives.

3.4 Cooling Towers and Pumps

There were four induced-draft type cooling towers with 30-hp fan motors: CT16-1, CT16-2 CT16-3 and CT16-4. The tower fans were provided with variable speed drives controlled by tower leaving water temperature (condenser water supply temperature). Two cooling towers were in operation at the time of the study.

The cooling towers were served by three 40-hp cooling tower pumps: CTP16-1, CTP16-2, and CTP16-3. A fourth cooling tower pump, CTP16-4 was being added at the time of the survey. The cooling tower pumps were constant speed and stage controlled by the building condenser water temperature demand through the facility ALC. The average central plant pump and tower fan power demand for the monitoring period was 92 kW.

3.5 Standby Generators, UPS and Data Center PDU's

There was no standby generator or UPS associated with this data center. Likewise, there was no Power Distribution Unit typically observed in a data center.

3.6 Computer Room Air Handlers

The data center was served by three 20-ton CRAH units in operation during the survey period. Each unit had two 7.5-hp constant speed fan motors. Based on data taken at the time of the survey, CRAH power consumption for unit CAH 1.5 was 0.84 watts per unit of airflow rate at one ft^3/min. The variation of minimum to maximum power draw was under 4% during the period.

The data center was served by seven 30-ton CRAH units. Each unit has two 7.5-hp constant speed fans and delivers approximately 15,000 cfm based on manufacturer's specification (13,400 cfm by calculation). Based upon data taken at the time of the survey, AHU power consumption was 0.62 W/cfm using the rated airflow, and 0.69 W/cfm using the calculated airflow rate.

3.7 Data Center Power Supply

The power to the racks was provided by a number of panel boards within the data center supplied from four distribution panels via four distribution transformers. The distribution transformers were rated at 225 kVA each (or 220 kW at an assumed data center power factor of 92%).

The total power consumption of the 440 data center racks, including transformer losses was 520 kW. The average power per rack was 1.2 kW. One rack was monitored over a week period. The average power consumption of the rack being monitored was 0.925 kW. For the selected rack, the minimum value of power consumption was 99% of the maximum value, indicating that the rack power was essentially constant.

4 System Operation

During the two-week monitoring period, the following HVAC equipment was operating:

- Two of three primary chilled water pumps
- One of two secondary chilled water pumps
- Chillers CH-1 and CH-2
- Two of three cooling tower pumps

- Two of three cooling towers
- All seven data center air handling units

4.1 Ambient Air Temperature and humidity

Figure 4 shows the ambient air temperature and relative humidity during the monitoring period. The average ambient temperature was 55°F, with highs of 77°F and lows of 36°F. The average relative humidity was 64% RH.

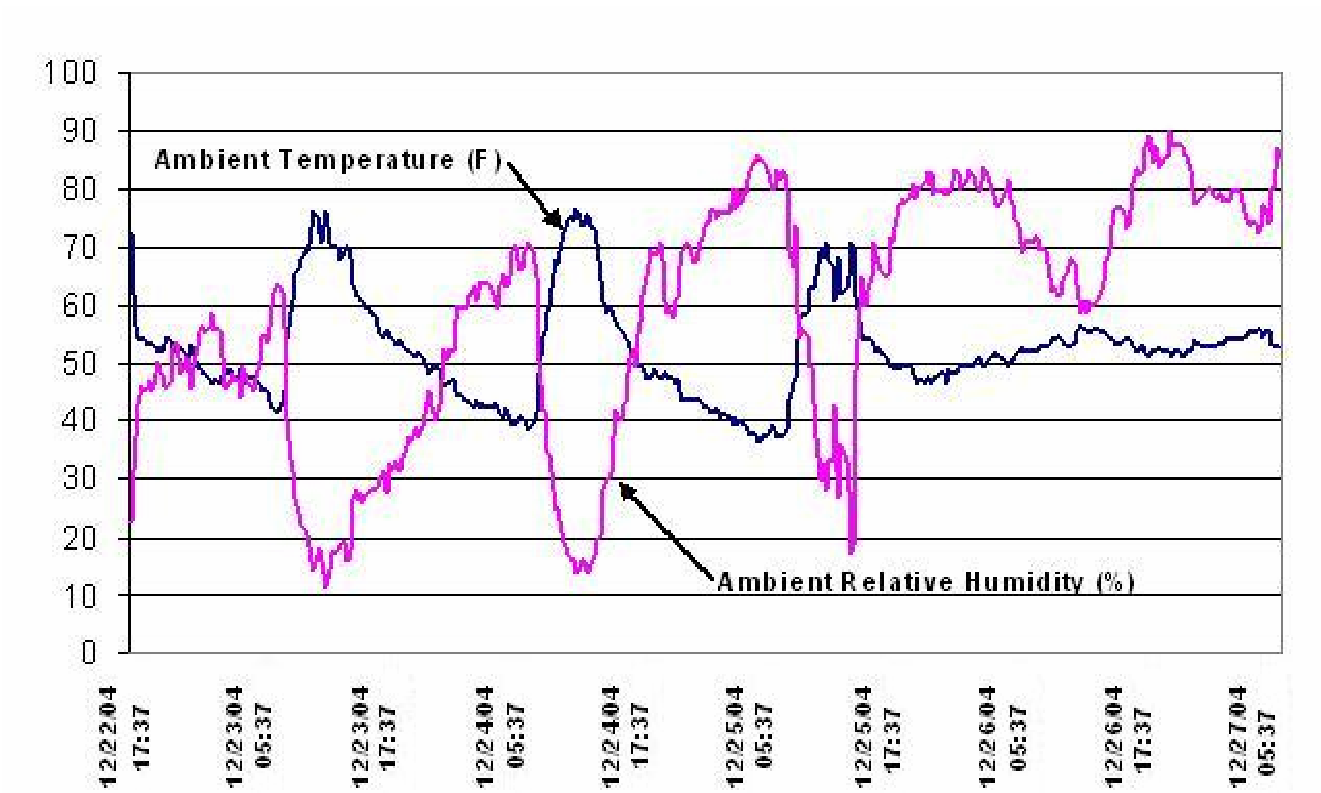

Figure 4 Ambient air temperature and humidity

4.2 Chilled Water Supply and Return Temperatures

The chilled water supply and return temperatures were monitored in the study. The data center chilled water temperatures were shown in Figure 5 along with the corresponding ambient temperature.

The spikes of high supply and return chilled water temperatures between 12/14/04 and 12/15/04 as shown in Figure 5 were the result of chiller change-over that took place during the hours. The change-over process included a time delay as the chiller went through its self test start-up sequence.

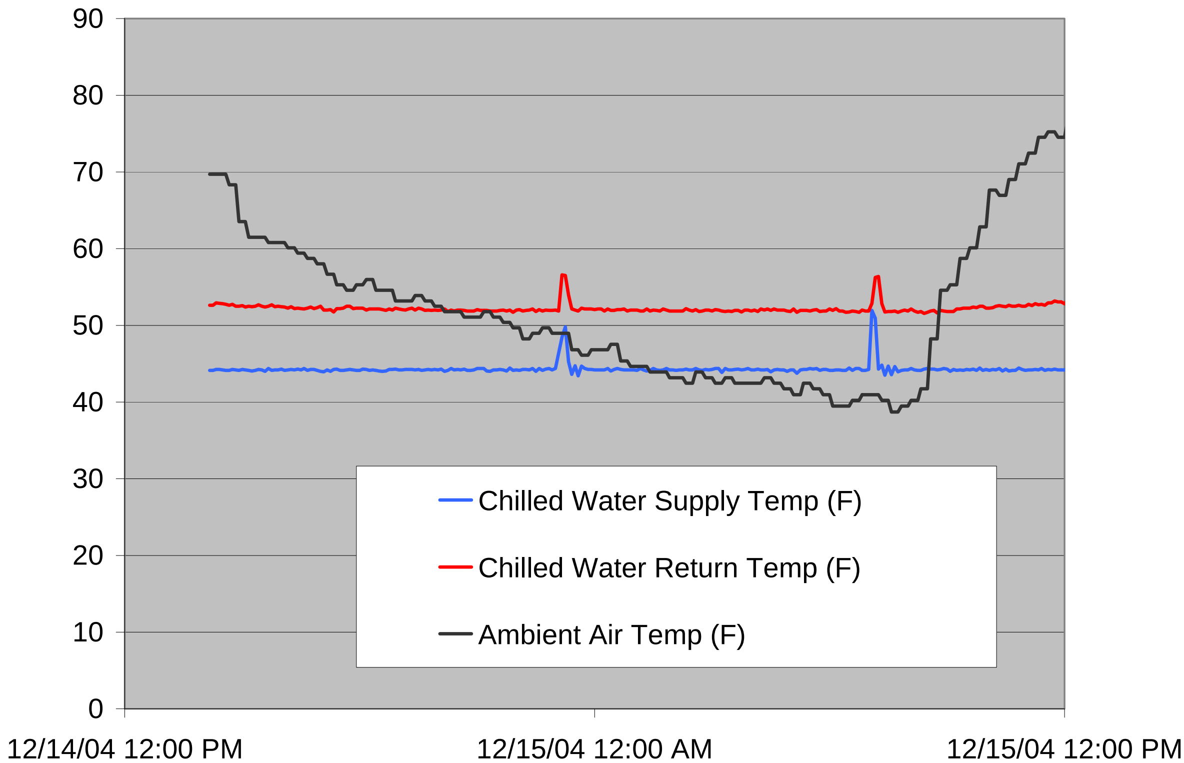

Figure 5 Chilled water and ambient air temperatures

4.3 Air Handling Unit Supply and Return Temperatures and Relative Humidity

Air temperatures and relative humidity for the supply and return airflows were monitored for one week during the study. The average temperatures are shown in Table 1.

Figure 6 shows air temperatures and relative humidity trending for 16CAH-5. The supply air temperature averaged 51°F, the return air temperature averaged 75°F, and the return air relative humidity averaged 28%. Similarly, Figure 7 shows air temperatures and relative humidity trending for 16CAH-6. The supply air temperature averaged 51°F, the return air temperature averaged 75°F, and the return air relative humidity averaged 29%.

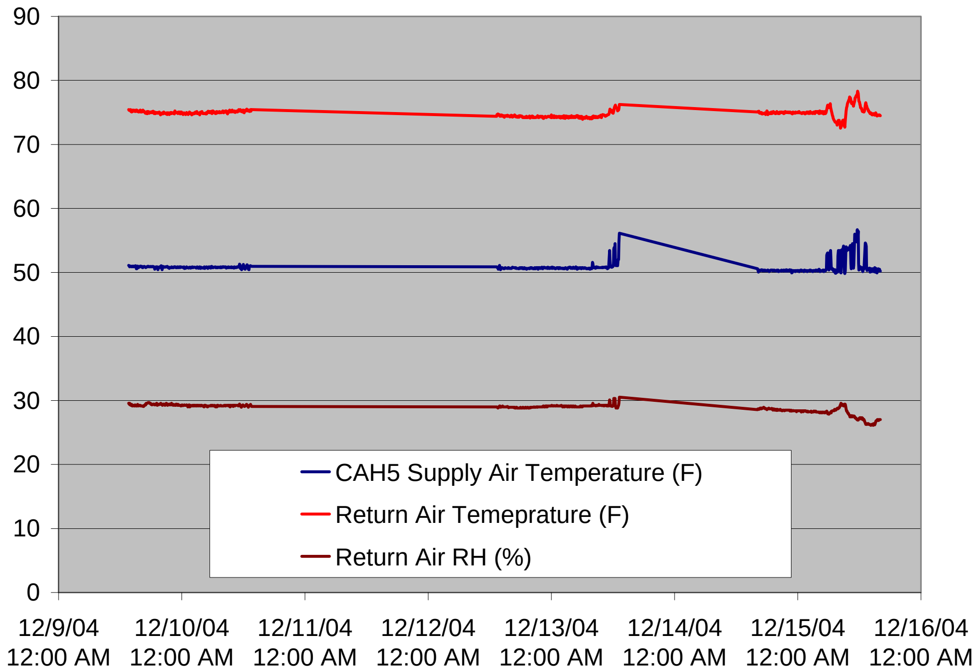

Figure 6 CAHU16-5 Supply, Return Temperatures and Relative Humidity

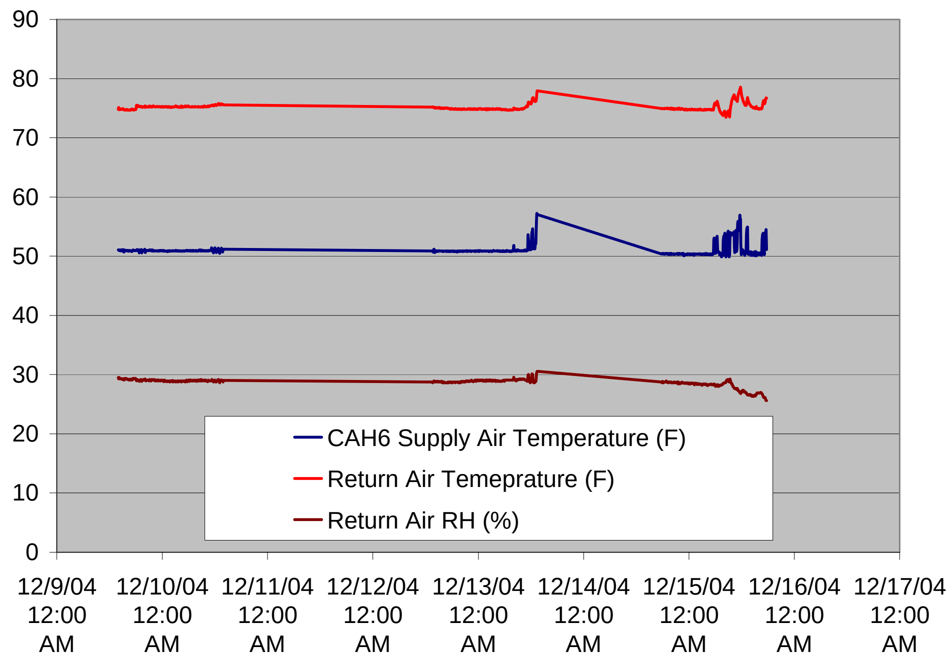

Figure 7 CAHU16-6 Supply, Return Temperatures and Relative Humidity

In addition, Figure 8 shows the temperature and relative humidity trending for 16CAH-8 The supply air temperature averaged 55°F, the return air temperature averaged 73°F, and the return air relative humidity averaged 36%.

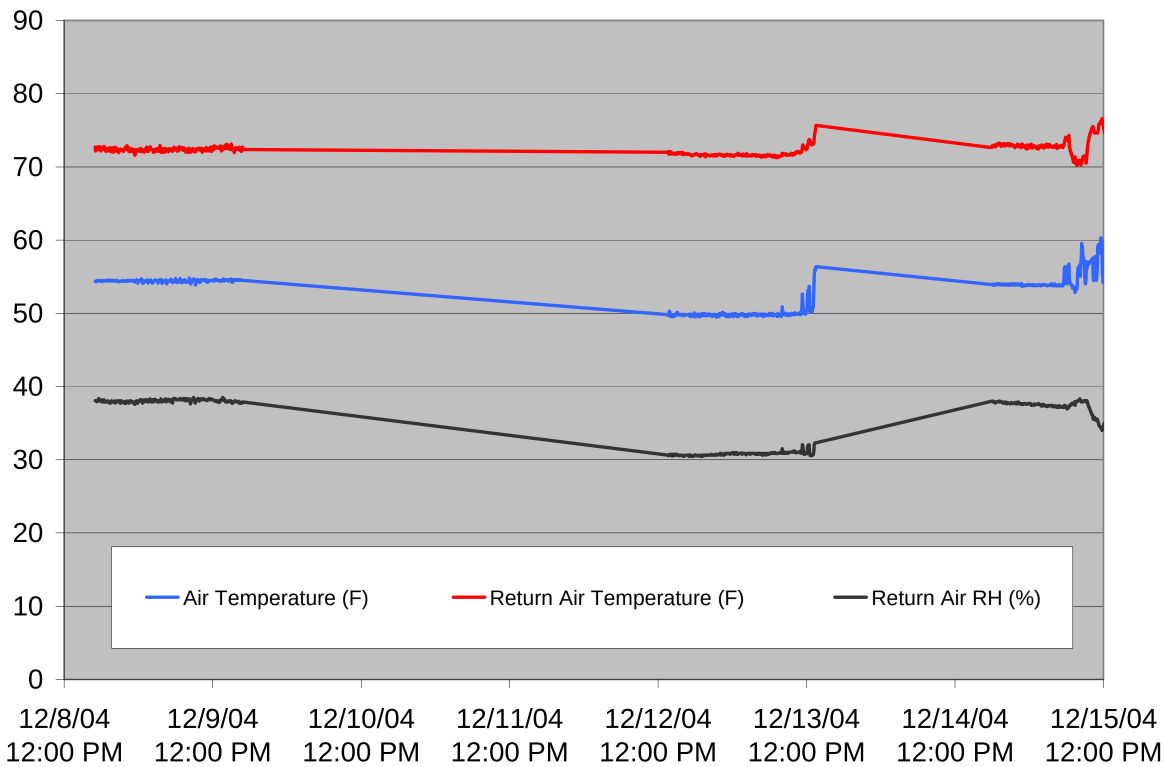

Figure 8 CAHU16-8 Supply, Return Temperatures and Relative Humidity

4.4 Data Center Space Air Temperature and Relative Humidity

The space temperature and relative humidity were monitored and shown in Figure 10. At one location the average space temperature and relative humidity was 71°F and 25% RH, respectively. At another location, the air temperature was 79°F with relative humidity of the 25% RH. The overall average space temperature was 75°F, and average relative humidity was 25%.

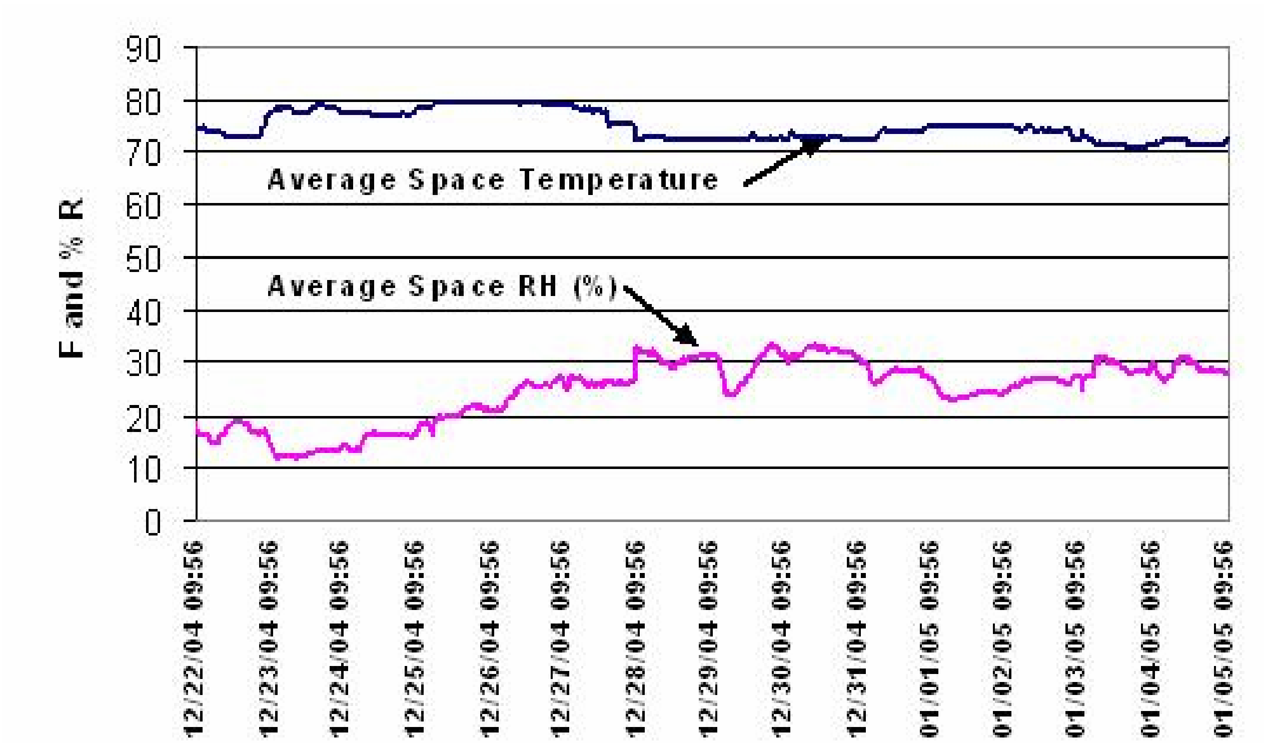

Figure 9 Data center air temperature and humidity

5 Observations and Recommendations

This data center was a rack test lab and was similar to DC 20. Both data centers didn't have electrical losses associated with UPS, standby generators, and redundant on-line equipment. DC 20 had a total power density of approximately 88 W/ft^2, while DC 21 had a total power density of approximately 84 W/ft^2. The IT power density was 61 W/ft^2 and 63 W/ft^2 for DC 20 and DC 21, respectively. watts/sf for DC 21. Corresponding to a slightly higher computer (IT) power density in DC 21, the overall power density for DC 21 was in fact lower than the overall power density in DC 20. This was in part due to 1) higher-efficiency water cooled chiller system that resulted in lower power density (i.e., 9 W/ft^2 in DC 21 compared with 14 W/ft^2 in DC 20); and 2) lower data center lighting power density in DC 21. In addition, The total power consumption per ton of heat load for the chillers and the central plant for DC 20 was approximately 22% greater than for DC 21 (0.73 kW/ton versus 0.6 kW/Ton). Interestingly, the power consumption per ton of heat load for the CRAH units of DC 20 (0.48 kW/ton) was 30% higher than that for the CRAH units of DC 21 (0.37 kW/ton).

The density of installed computer loads (rack load) in the data center studied was 61 W/ft^2. The building and its data center cooling system was provided with various energy optimizing systems that included the following:

- Varying chilled water flow rate through variable speed drives on the primary pumps.
- No energy losses due to nonexistence of UPS or standby generators.
- Minimized under-floor obstruction that affects the delivery efficiency of supply air.
- Elimination of dehumidification/humidification within the CRAH units.

General recommendations for improving overall data center energy efficiency include improving the lighting control, design, operation, and control of mechanical systems serving the data center in actual operation. This includes chilled water system, airflow management and control in data centers. The following additional techniques should result in significant improvements in energy efficiency, effective operation, or both.

5.1 Lighting

The measured lighting load in the Data center was 10 kW with an intensity of 1.2W/ft^2. The lighting power can be reduced by considering the following energy control measures: install lighting zone occupancy sensors; and task lighting in appropriate areas and disable portions of overhead lights where light was not needed.

5.2 Airflow Optimization

5.2.1 Floor Tile Rearrangement

An analysis in airflows through tiles was performed based on the CRAH unit locations, perforated tile locations, and the computer rack locations. At some locations in the data center, airflow rates through the perforated tiles was relatively low, potentially creating areas of higher temperatures - hot spots due to inadequate heat removal. In Figure 10, the small colored squares represent the perforated tiles. The colors of the squares indicate the relative airflow rates through the tiles: darker blue indicates higher airflow rates; while lighter blue indicates lower airflow rates, and yellow-to-amber indicates even lower airflow rates. From the analysis, it is recommended that some of the perforated tiles in the data center should be re-arranged to induce more effective air distribution in the space, reducing occurrence of hot spots. In addition, additional analysis of the airflow should be conducted based on modifications to tile arrangements.

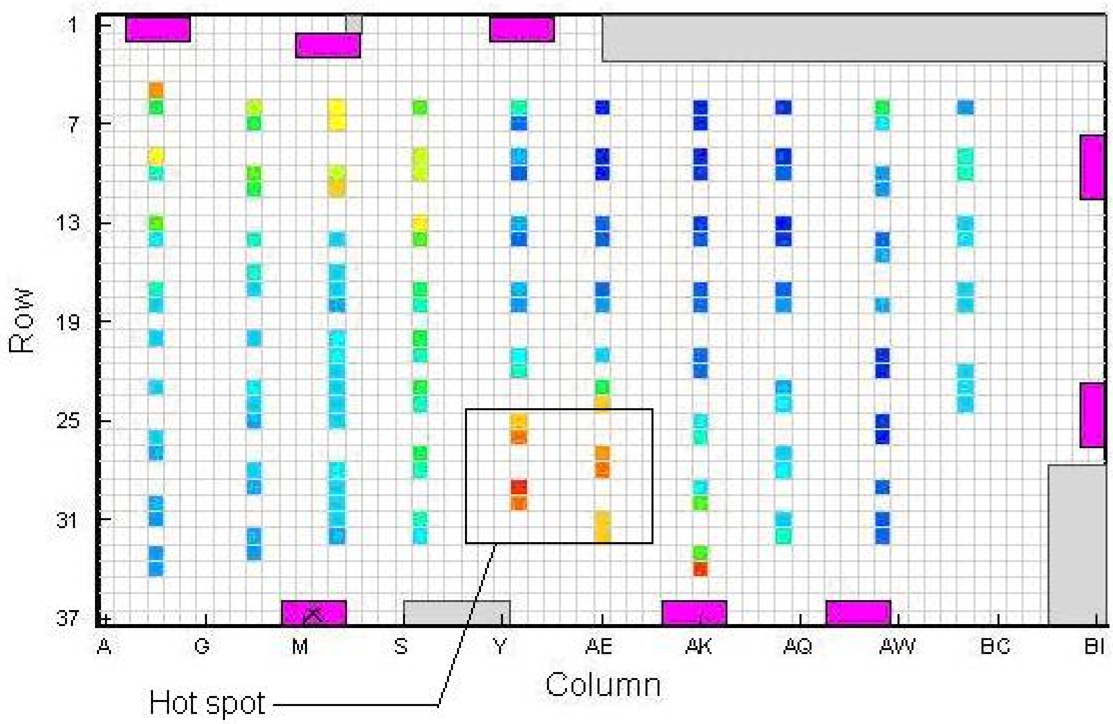

Figure 10 Airflow rates through perforated tiles and hot spots

In summary, cold air was un-evenly distributed throughout the data center. Either blocking unwanted openings on the raised floor or reducing airflow rates using adjustable dampers, or increasing tile perforation in the areas with limited air supply would result in a more even air distribution, thus reducing potential hot spots in the data center.

5.2.2 Wiring Configuration

Cables hanging in front of computer racks caused undesirable airflow deviations in cooling the rack equipment. These communication cables should be properly managed in front of the server or re-routed to the back of the equipment in order to reduce air circulation restrictions, because cold air is drawn through the front of the server to the backside of the server. Adding blank-offs within and between racks could prevent air bypasses and undesired mixing between hot and cold air flows.

5.2.3 Rack Air Management

The lack of delineated hot aisles and cold aisles layout was a significant impediment to proper air distribution in the data center. In hot-cold aisle configurations, racks would be installed in face-to-face and back-to-back configurations, with perforated tiles located below the face-to-face aisles, and no perforated tiles in the back-to-back aisles. Warmer return air would be drawn from the hot aisles by the CRAH unit supply fans, routed through the cooling coil and supplied back into the raised floor plenum.

A primary recommendation for the rack layout is that cold supply air should flow from the front to the rear of the IT equipment. The study recommends to arrange fronts of equipment on each side of a cold aisle face each other and the backs of equipment in adjacent aisles (hot) facing each other. The cool air entering the front of the computer servers forms a common cold aisle and, warm air discharging at the rear of the servers forming a common hot aisle.

5.3 Air Temperature and Relative Humidity

The recorded data center ambient air's relative humidity ranged between 15% and 35% RH. Changing chilled water supply temperatures may affect relative humidity in the data center: Higher supply water temperatures may correspond to higher air humidity in the space, and would increase the chiller efficiency. The desired air temperatures in the data center were between 71°F and 73°F and a relative humidity between 45 and 50%. To achieve these conditions it is recommended that the supply air temperature from the CRAH units be maintained at 55°F. This would require that the current control on return air temperature be changed to control on supply air temperature. The IT equipment specifications should be reviewed regarding inlet air temperature requirements. With improved air management, it is likely that supply air temperatures from the CRAH could be increased, with resultant chiller plant efficiency improvement and better humidity control.

The CRAH unit manufacturer's specifications should be compared with the present CRAH unit operating conditions to determine what the cooling capacity would be under the proposed operating condition (higher supply air set point and higher chilled water temperature). Additionally, the IT equipment specifications about air humidity requirements should be compared against the actual operating conditions to determine whether further humidification would be required. If no equipment reliability problems had been experienced due to the lower humidity than 45%RH, then it is probably unnecessary to humidify the space within the data center.

5.4 Chilled Water System

Chiller plant optimization should be considered, including control tuning and reset of chilled water and tower water temperatures. For example, setting the chilled water supply temperature to 50°F may provide sufficient sensible cooling in the data center. In the meanwhile, chiller energy consumption would be reduced due to improved operating efficiency. In addition, chiller plant optimization also involves optimizing the interaction between tower fan, condenser water pump, and chiller power to achieve the lowest overall chiller plant power at any given load and ambient condition. As part of this strategy, consideration should be given to adding variable speed drives to the primary chilled water pumps and the tower water pumps.

6 Acknowledgements

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7 Appendix A: Data Facility Definitions and Metrics

The following definitions and metrics are used to characterize data centers:

Air Flow Density	The air flow (cfm) in a given area (sf).
Air Handler Efficiency 1	The air flow (cfm) per power used (kW) by the CRAC unit fan.
Air Handler Efficiency 2	The power used (kW), per ton of cooling achieved by the air-handling unit.
Chiller Efficiency	The power used (kW), per ton of cooling produced by the chiller.
Computer Load Density – Rack Footprint	Measured Data Center Server Load in watts (W) divided by the total area that the racks occupy, or the "rack footprint".
Computer Load Density per Rack	Ratio of actual measured Data Center Server Load in watts (W) per rack. This is the average density per rack.
Computer/Server Load Measured Energy Density	Ratio of actual measured Data Center Server Load in watts (W) to the square foot area (sf) of Data Center Floor. Includes vacant space in floor area.
Computer/Server Load Projected Energy Density	Ratio of forecasted Data Center Server Load in watts (W) to the square foot area (sf) of the Data Center Floor if the Data Center Floor were fully occupied. The Data Center Server Load is inflated by the percentage of currently occupied space.
Cooling Load – Tons	A unit used to measure the amount of cooling being done. One ton of cooling is equal to 12,000 British Thermal Units (BTUs) per hour.
Data Center Cooling	Electrical power devoted to cooling equipment for the Data Center Floor space.
Data Center Server/Computer Load	Electrical power devoted to equipment on the Data Center Floor. Typically the power measured upstream of power distribution units or panels. Includes servers,

	switches, routers, storage equipment, monitors and other equipment.
Data Center Facility	A facility that contains both central communications and equipment, and data storage and processing equipment (servers) associated with a concentration of data cables. Can be used interchangeably with Server Farm Facility.
Data Center Floor/Space	Total footprint area of controlled access space devoted to company/customer equipment. Includes aisle ways, caged space, cooling units electrical panels, fire suppression equipment and other support equipment. Per the Uptime Institute Definitions, this gross floor space is what is typically used by facility engineers in calculating a computer load density (W/sf).
Data Center Occupancy	This is based on a qualitative estimate of how physically loaded the data centers are.
Server Farm Facility	A facility that contains both central communications and equipment, and data storage and processing equipment (servers) associated with a concentration of data cables. Can be used interchangeably with Data Center Facility. Also defined as a common physical space on the Data Center Floor where server equipment is located (i.e. server farm).

8 Appendix B: Facility Diagrams

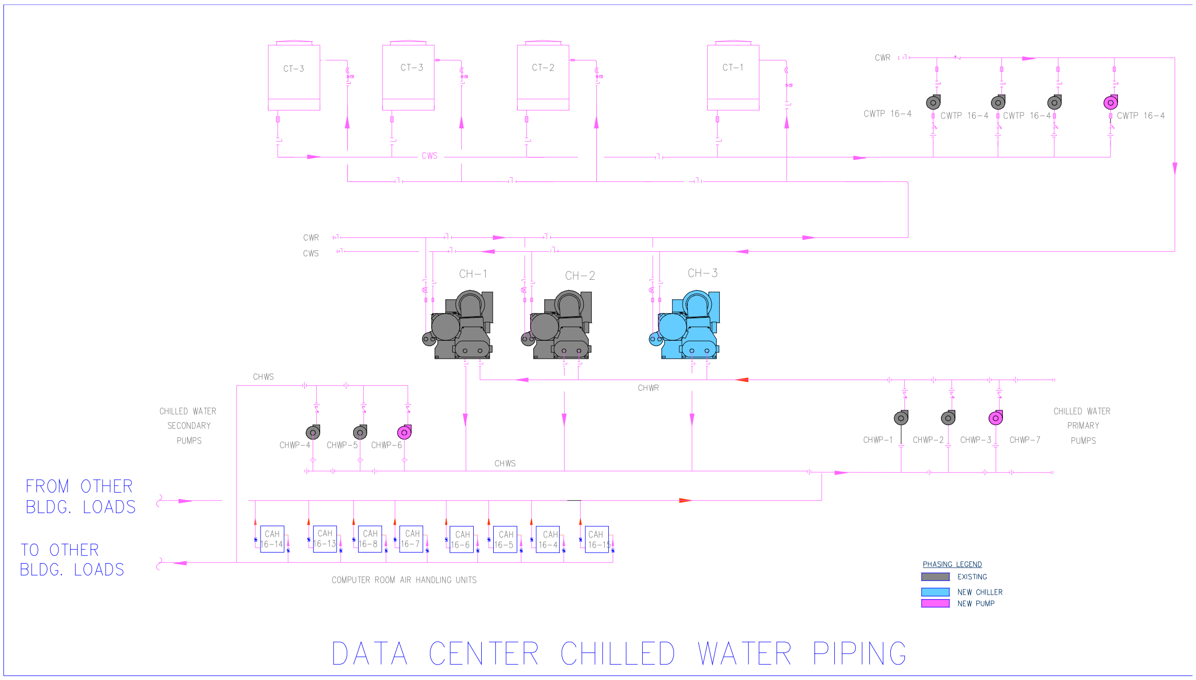

Figure 11 Chilled Water System

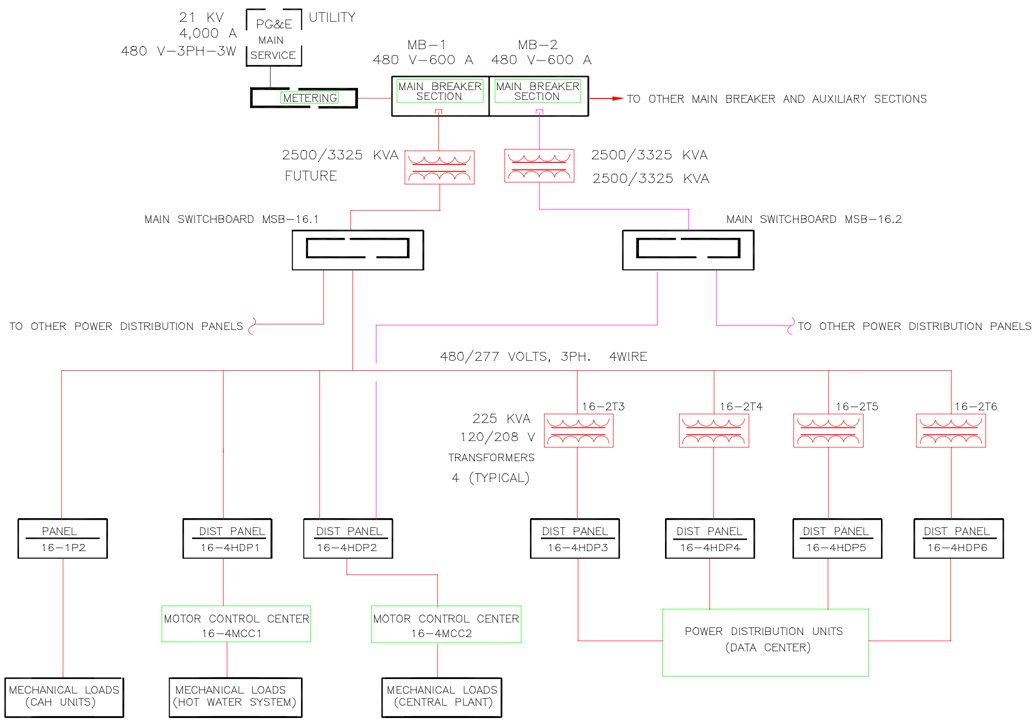

Figure 12 Electrical System Schematic